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18 separate items enclosed

10 JI CA 9?

TP-FY99-0092

✓ Spreadsheet
✓ DTI

MEMORANDUM FOR PRR (~~Contractor~~/In-House Publication)

FROM: PROI (TI) (STINFO) 18 May 1999

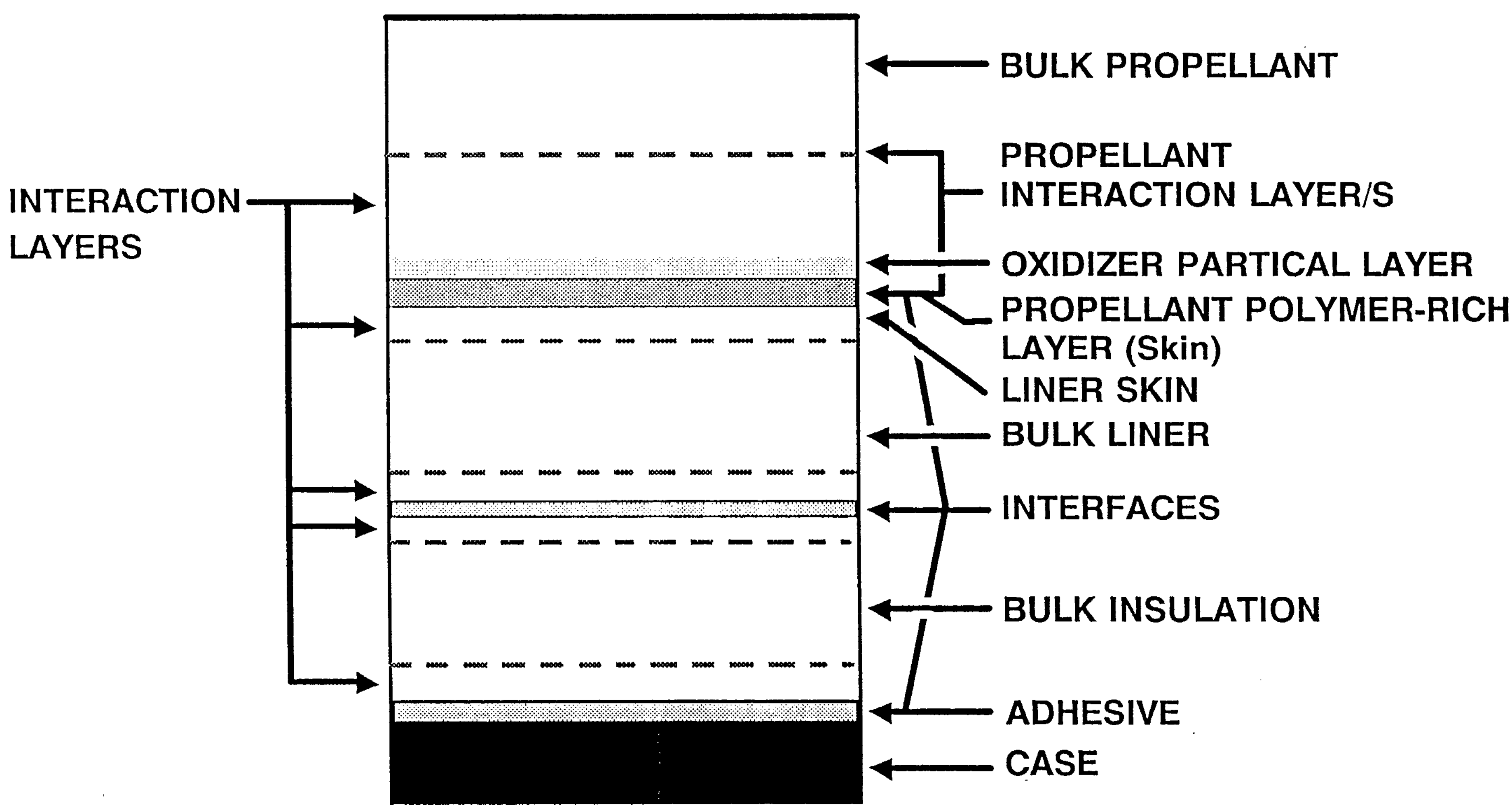
SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0092
C.T. Liu "2302M1 Fracture Mechanics and Service Life Prediction Research"
U of Illinois at Urbana/Champagne Team Presentation **(Statement A)**

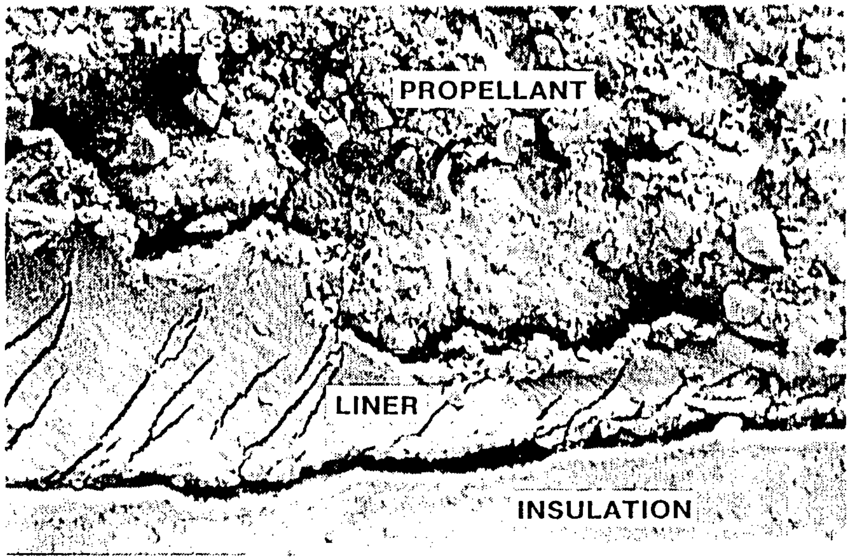
2302M1 Fracture Mechanics and Service Life Prediction Research

Dr. C. T. Liu

Air Force Research Laboratory
Edwards AFB

Propellant/Liner/(Barrier)/ Insulator/ Case BONDING....





(a) 0 mm STRESS

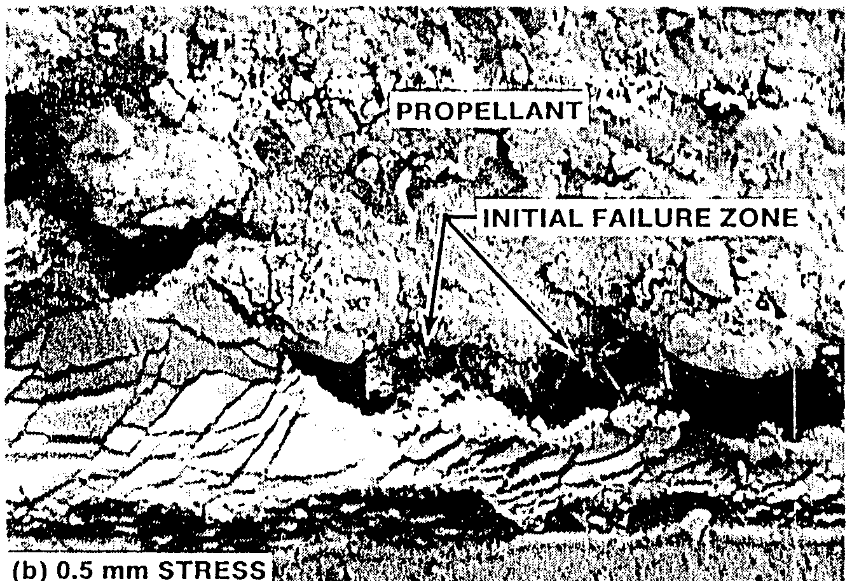
05KU 46.1X 217P 0007 3066

A SERIES OF SEM PHOTOGRAPHS AS STRESS (TENSILE) IS GRADUALLY INCREASED ON AN ANB 3066 (SD-851) INTERFACE;

(a) INITIAL (NO STRESS)

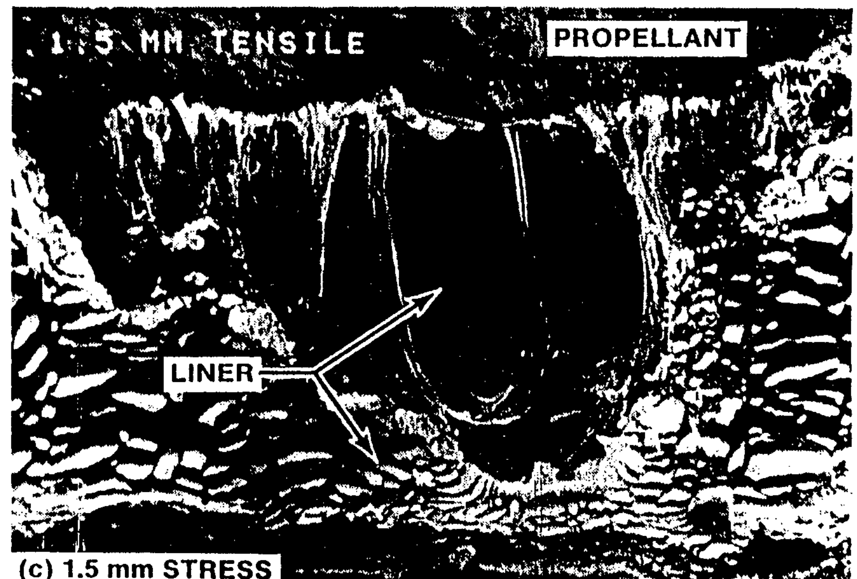
(B) LOW LEVEL OF STRESS

(c) INTERMEDIATE STRESS



(b) 0.5 mm STRESS

05KU 46.0X 217P 0008 3066



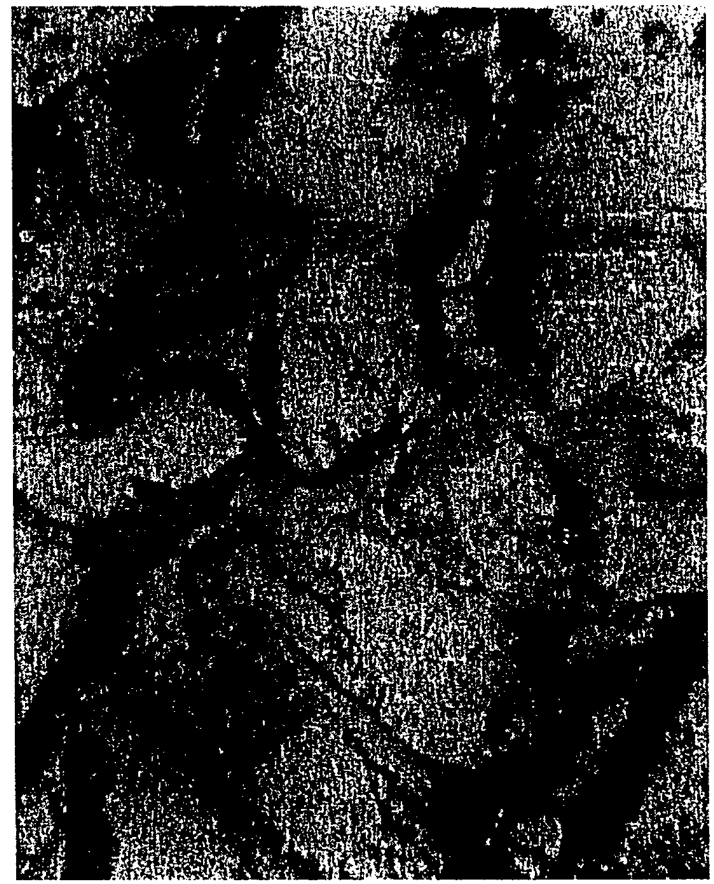
(c) 1.5 mm STRESS

05KU 45.7X 219P 0014 3066

Local Dewetting About Filler Particles in Propellant

← Direction of Strain →

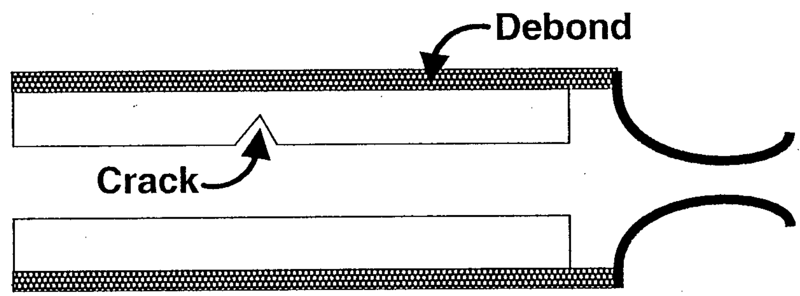
Unstrained



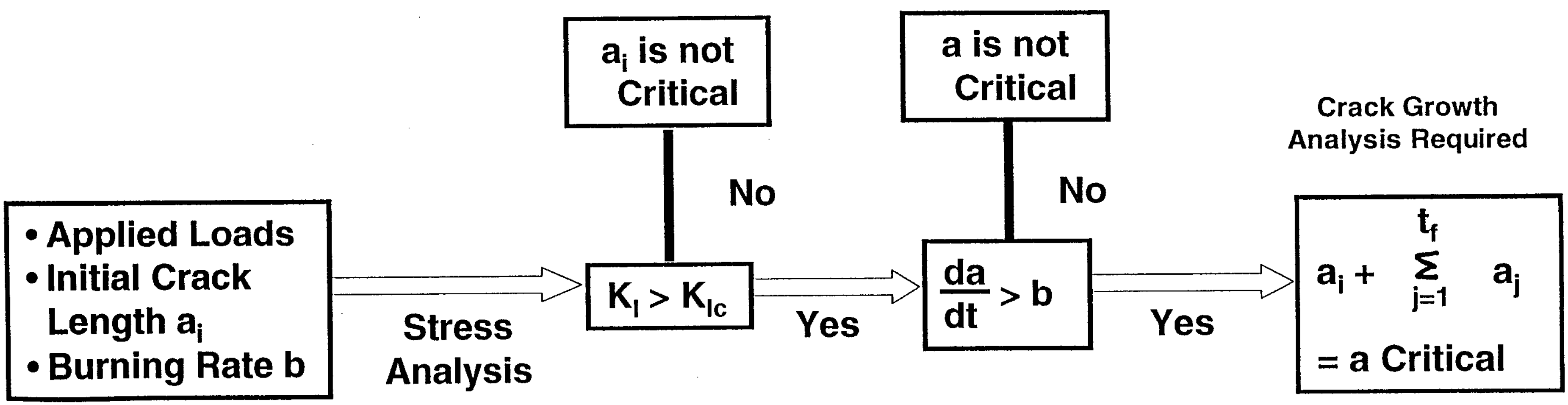
30% Strain

A2598.

Two Crack Failure Modes in Solid Rocket Motors



- Does Crack Propagate Under Service Loads?
- If the Crack Propagates, How Does it Propagate?



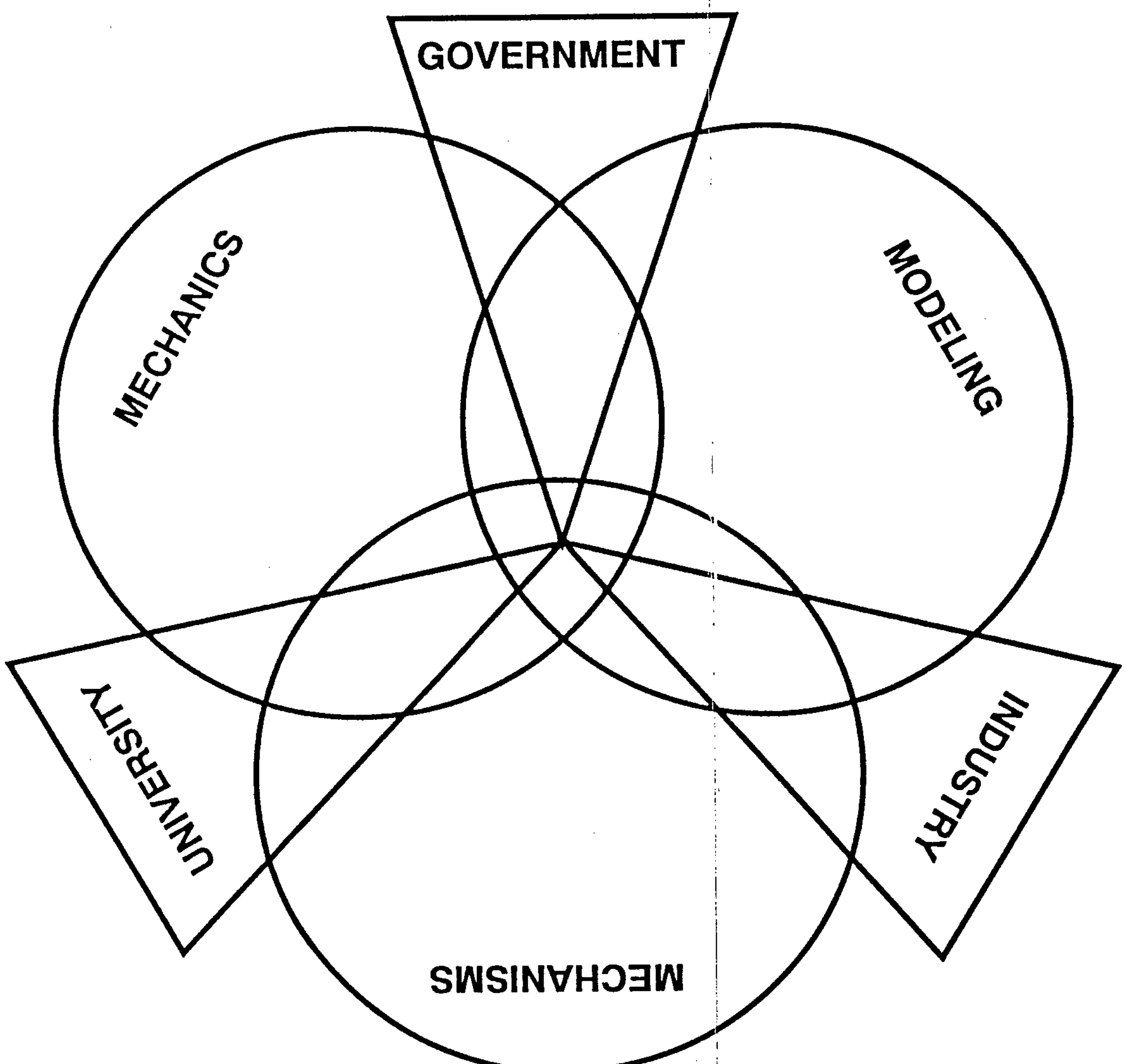
Deficiencies of Current Structural Design and Service Life Prediction Methodologies

- The Current Crack Initiation Criterion Does Not Adequately Define the Ultimate Strength and the Ultimate Service Life of Solid Rocket Motors

- The Lack of a Fundamental Understanding of Crack Growth Behavior Under Service Loading Condition and a Reliable Methodology to Predict Crack Growth has Severely Restricted the Ability to Predict Motor's Service Life

A0753.01

Approach....



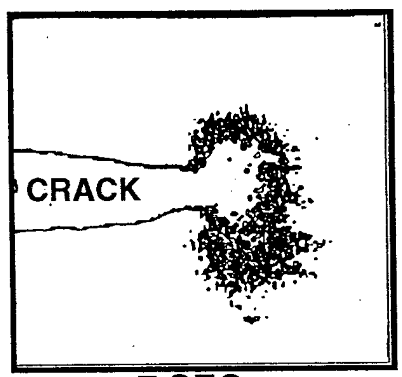
The Effect of Damage on Crack Growth Behavior Depends on Damage Intensity and Applied Loading Rate

(A) Crack Growth Velocity Decreases When the Crack Enters the Damaged Region

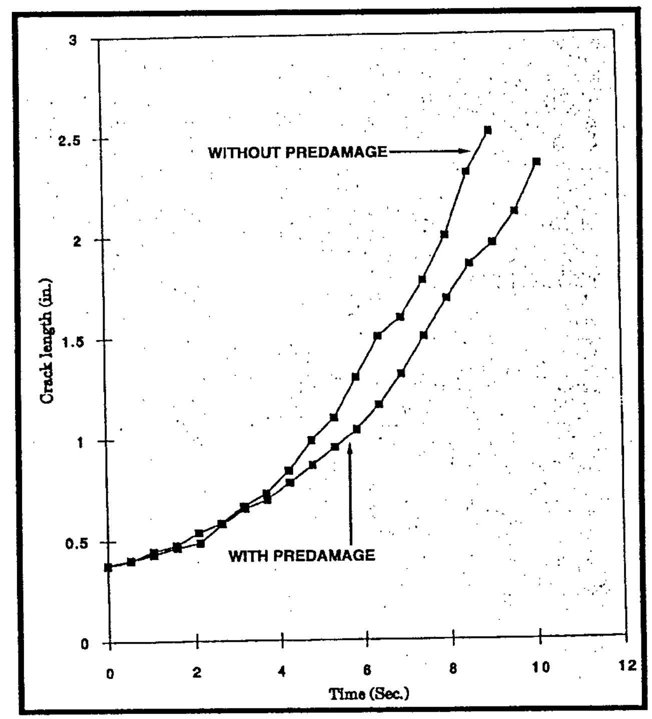
(B) A Severely Damaged Region has no Significant Effect on Crack Growth Behavior

(C) The Preexisting Damage May Change the Criticality of the Crack

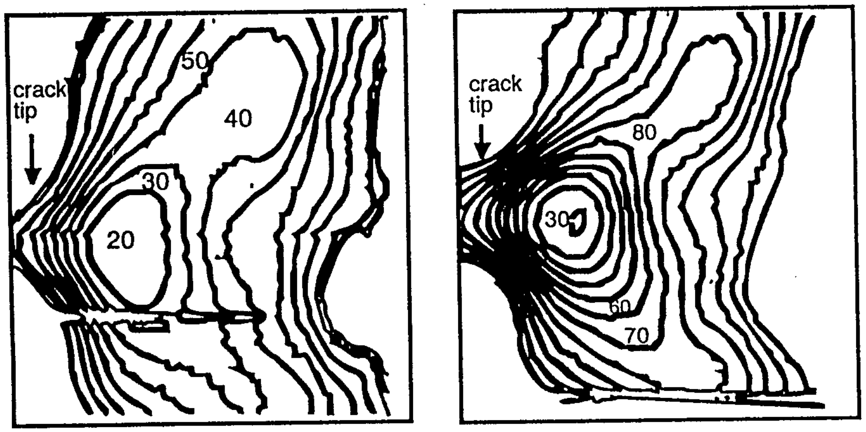
4 SEC.



7 SEC.

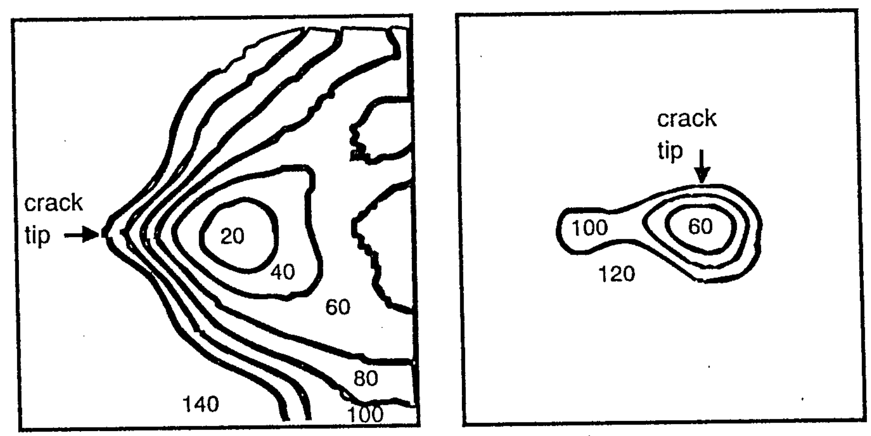


Time and Load History Dependence of Damage Characteristics Near the Crack Tip....



a. b.

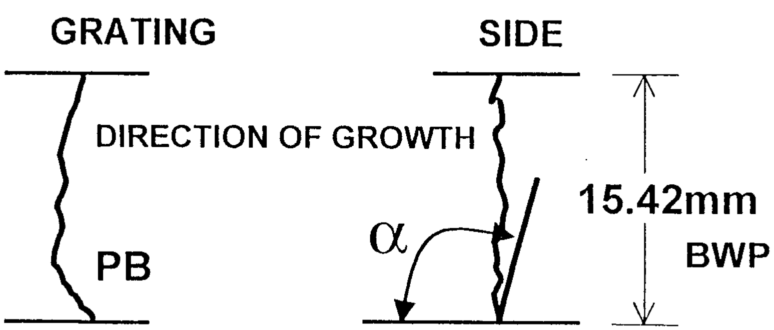
Iso-Intensity Contour Plots of Acoustic Imaging Near the Crack Tip (a. was Taken Before the 10 Strain Cycles and b. was Taken After the 10 Strain Cycles)



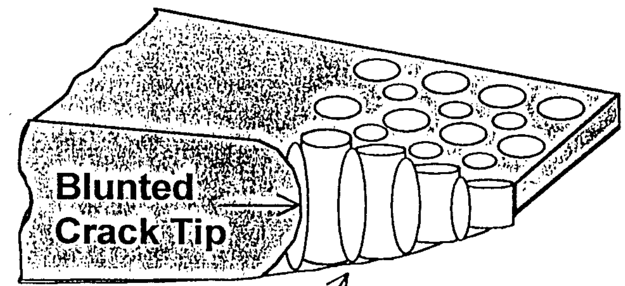
a. b.

Iso-Intensity Contour Plots of Acoustic Imaging Near the Crack Tip ($\varepsilon = 0\%$, b was Taken 65 Hours After a.)

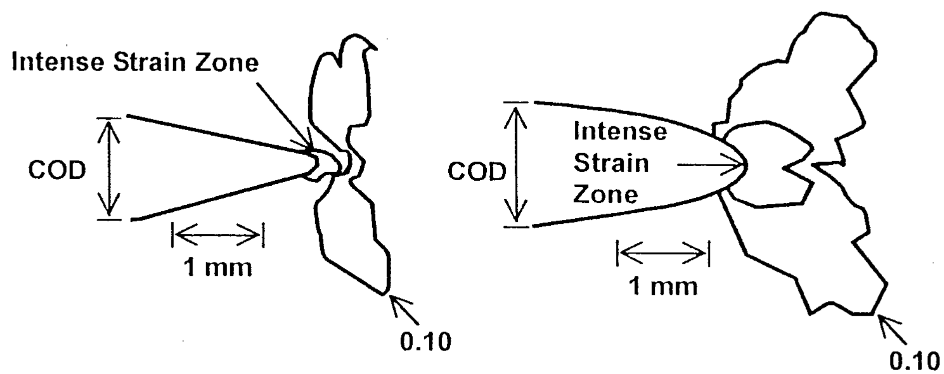
No Thumbnailing Observed in Either unfilled Binder of Corresponding Solid Propellant During Opening of Growth of Crack



CRACK FRONT SHAPE



Intense Strain Zone
Idealized Strain Zone
Producing Crack Tip
Blunting in BWP Specimens



PB, $\varepsilon_Y = 4.7\%$ BWP, $\varepsilon_Y = 4.0\%$

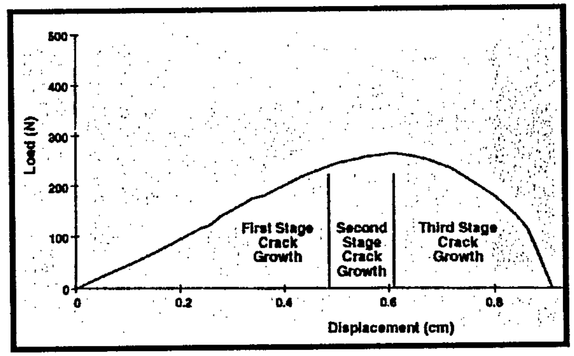
Local Distribution of Strain (ε_y)
Normal to Crack Plane (Head Rate 2.5 mm/sec)

- A Local Plane Strain Constraint May Not Exist
- Sever Blunting Occurs in the Solid Propellant Which Inhibits Cracked Growth Relative to that in the Binder Material

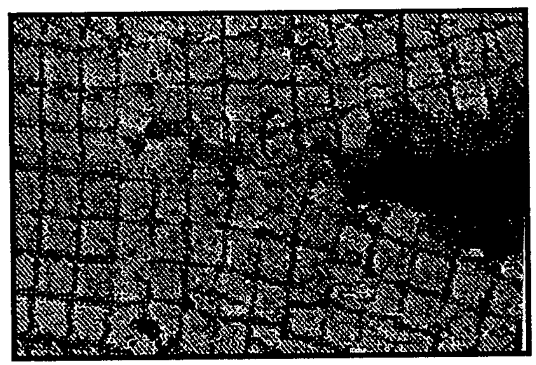
A Change in Damage Characteristics Affects the Crack Opening Displacement, Failure Process Zone Size, and Crack Growth Behavior

(A) Time Dependent Damage Evolution and Crack-Damage Interaction Processes are Responsible for Time Dependent Crack Growth Behavior

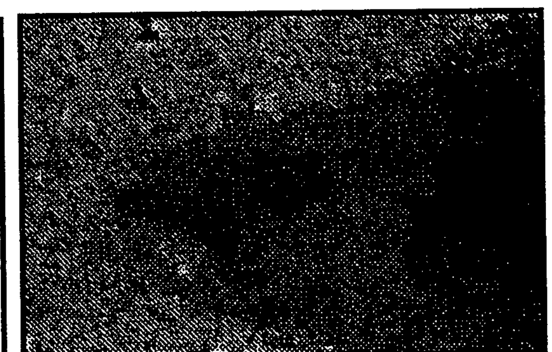
(B) This Information Will Provide Guidance for Numerical Modeling of Crack Growth



First Stage of Crack Growth



Second Stage of Crack Growth



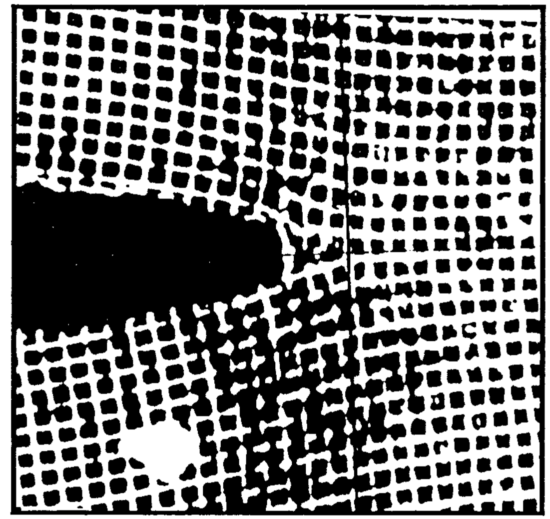
Third Stage of Crack Growth

Toughening Mechanisms Change With Temperature

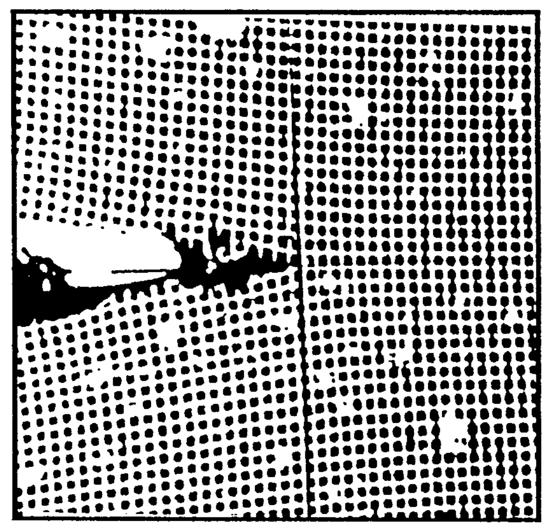
(A) At High Temperature,Toughening Mechanism is Associated With the Development of a Large Damage Zone at the Crack Tip

(B) At -65°F, Toughening Mechanism is Associated With the Increase in Particle / Binder Interface Strength and Binder Strength

(C) This Information Will Provide Insight into How to Increase the Fracture Toughness of Solid Propellants



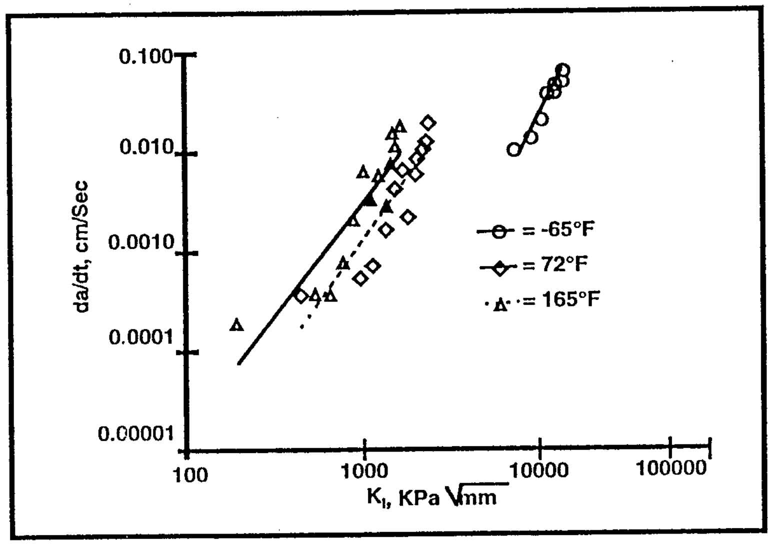
165°F



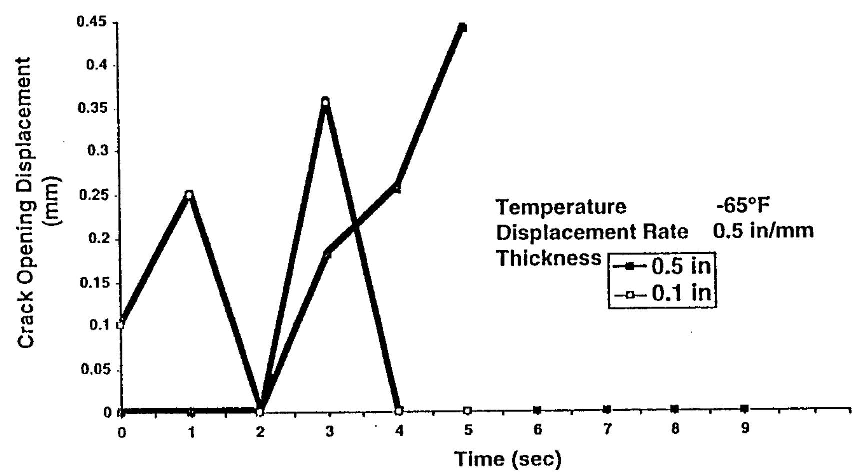
-65°F

Temperature Has a Significant Effect on Crack Growth Behavior

(A) A Power Law Relationship Exists Between the Crack Growth Rate and the Mode I Stress Intensity Factor as Predicted by the Probabilistic Crack Growth Model

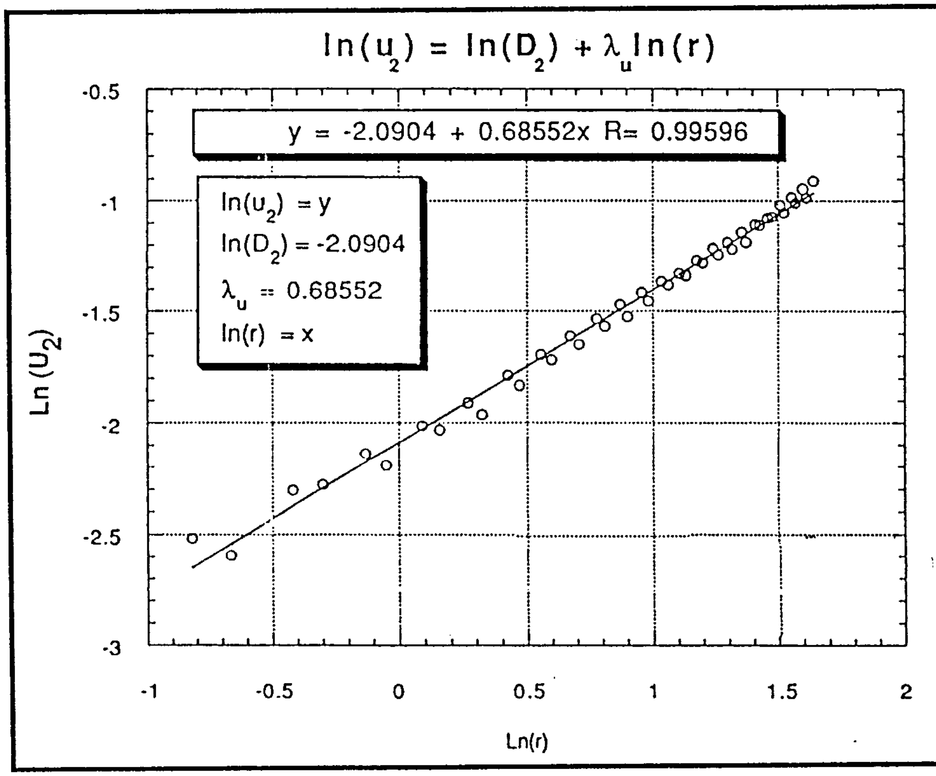


(B) At -65°F, the 0.5 in Thick Specimen Develops a High Transverse Constraint Near the Crack Tip, Resulting in a Classical Brittle Fracture



On the Macroscopic Scale, the Solid Propellant Studied Can be Considered as an Isotropic, Homogeneous Continuum

Temperature °F	Loading Rate (mm/min)	λu
-65	12.7	0.74
-65	2.54	0.78
72	12.7	0.65
72	2.54	0.66
165	12.7	0.74
165	2.54	0.77
	Average	0.72
	Theoretical Value =	0.67

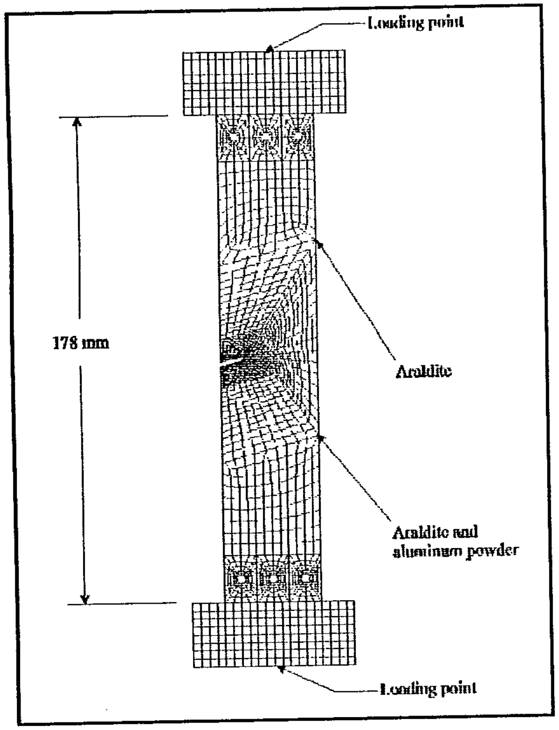


(A) A Good Correlation Exists Between the Measured and the Theoretical λu, Based on a Continuum Approach, Values of the Order of Singularity

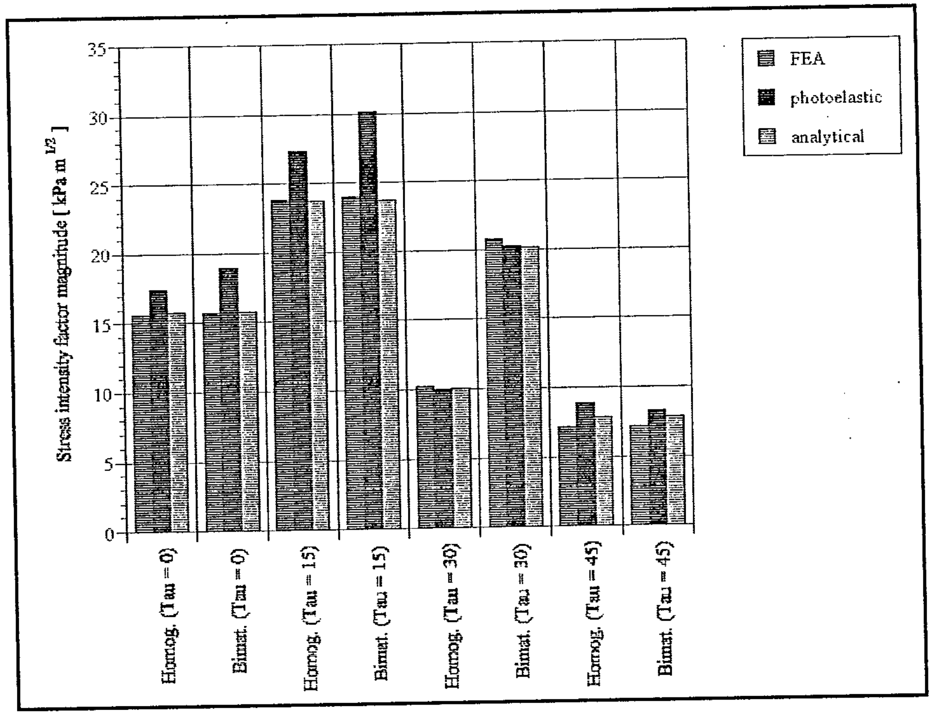
(B) This Information Provides Confidence in Using Continuum Approach to Determine Material Responses of the Solid Propellant Studied

Good Correlation Between Numerical and Experimental Results

Modeling of Incompressible Materials Under Plane Strain Conditions



Typical Bimaterial Specimen



Data for Stress Intensity Factor Magnitudes

$$J = \int_A [\sigma_{ij} u_{j,1} - W d_{1i}] q_{1,i} \, dA, \quad |K| = \sqrt{J\overline{E^*}}, \quad \overline{E^*} = \textit{Effective plane strain modulus}$$

Future Visions

- Transition of Crack Growth Prediction Technology to Research Community and Rocket Industry

- Interfacing of Crack Growth Prediction Technology with NDE Methodology

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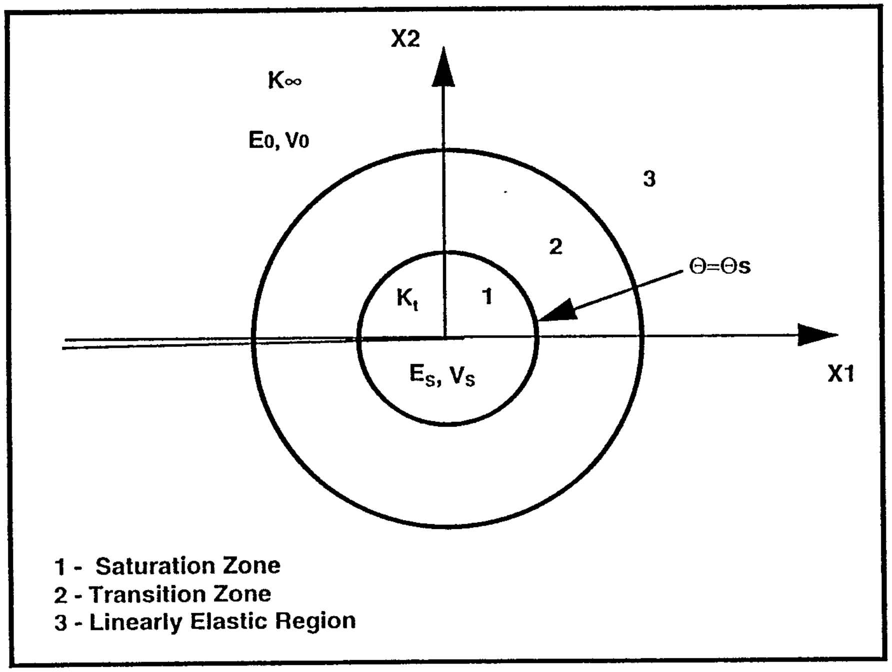
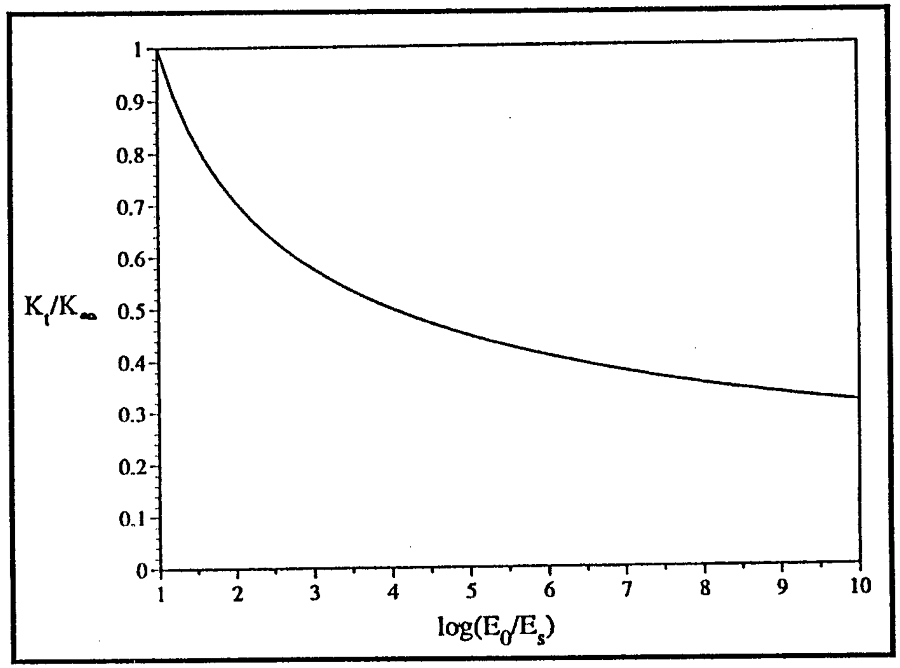
Crack Tip Damage Induces a Shielding Effect on Stress Intensity Factor K_I





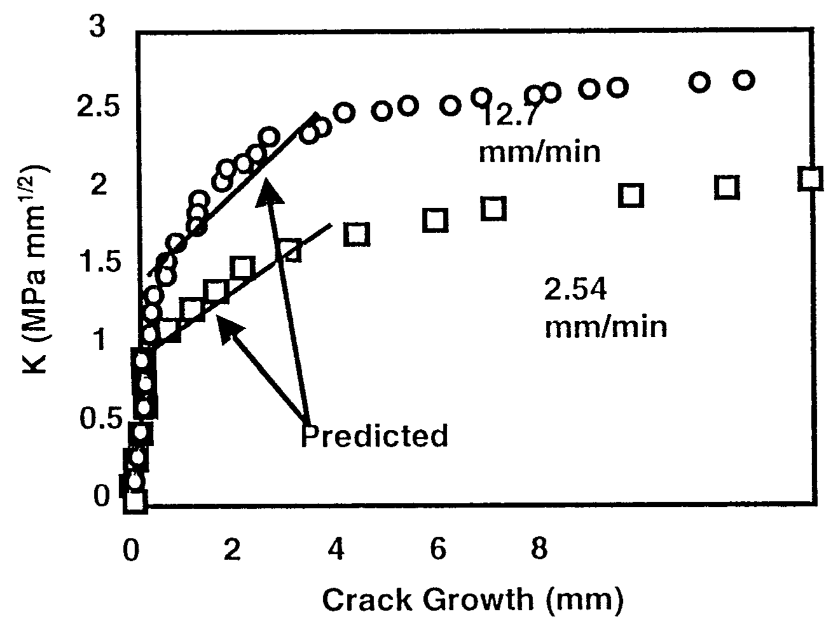
(a) The Extent of Shielding is Related to the Degree of Degradation of the Material in the Saturation Region

(b) The Variation of the Degree of Shielding is Responsible for the Fluctuations of the Crack Growth Rate

Numerical Modeling results Compare Well With Experimental Results

A) The Critical Damage Criterion Can be Used to Predict the Crack Growth Behavior

B) The Numerical Simulations are Able to Predict the Initiation Toughness (K_{IC}) and the Subsequent Stable Crack Growth



Comparison Between Predicted and Experimental Resistance (K Vs. Δ a) Curves for the Two Loading Rates, 2.54 mm/min and 12.7 mm/min.